Electrical Ignition

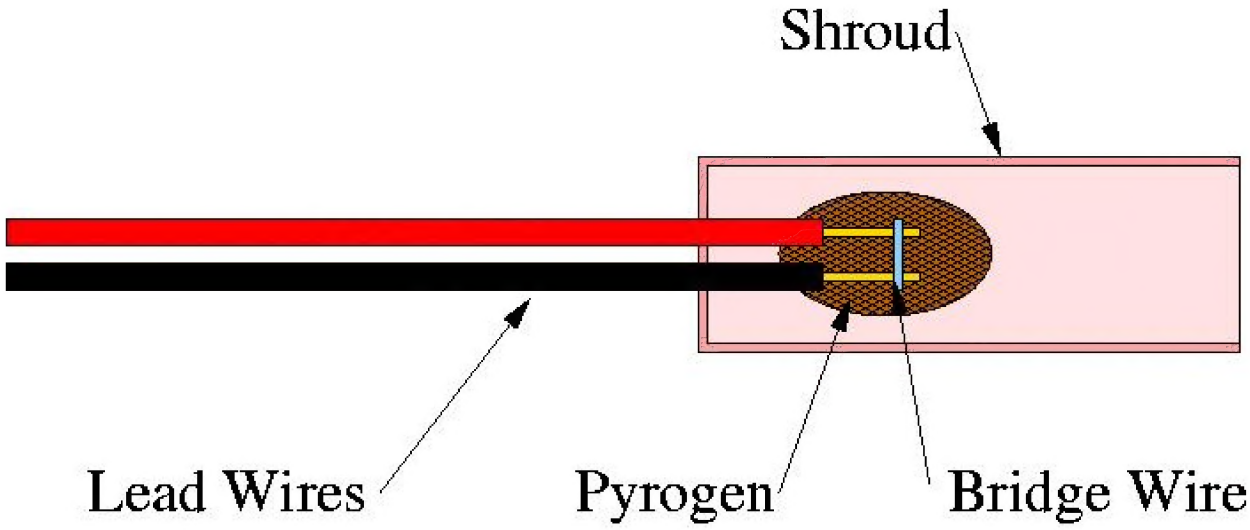
2005-01-16

Theory

Electrical ignition systems use the ohmic heating caused by an electrical current passing through a conductor to initiate a pyrotechnic composition. They are typically designed to produce a short burst of hot gases and sparks for initiating other compositions further down the pyrotechnic chain.

Electric igniters, "fuse heads", "electric matches" or "e-matches", do not detonate. They contain only low-explosives and will not initiate a secondary high-explosive. However a similar device containing a primary high-explosive in a metal tube is called an electrical detonator and is used to initiate high-explosives. A "squib" is neither an e-match or electrical detonator, but is more similar to the later and must never be used to replace an e-match. The term "squib" is unfortunately ambiguous and is best avoided IMO. In this text we will address only e-matches used for igniting low-explosive pyrotechnic devices.

Physically e-matches are two wires that come together at the pyrotechnic end of the device where a small blob of "pyrogen" composition is found. Within this blob of composition is usually a very fine "bridge wire", typically of nichrome alloy, that connects each of the lead wires. It functions purely as a heating element, its job is to reach the initiation temperature of the pyrogen and reliably initiate it. Some e-matches, so called "bridgeless" e-matches, have no bridge wire at all, the pyrogen is formulated to be conductive and forms its own bridge wire. Some e-matches come with a removable plastic shroud that protects the match head and can be used to direct the gases and sparks if required.



Electrically e-matches are essentially a pure resistive element. Typical values are 1.5 Ohms across the device. Commercial e-matches are rated by the "no-fire current" and the "all-fire current", the currents at which all units in a lot of devices won't "cook-off" and will reliably fire respectively. The no-fire current is typically 50 mA, and the all-fire current 500-1000 mA. The region between the all-fire and no-fire currents is undefined and must be avoided. The no-fire current is used for continuity test purposes in practical firing systems.

To reliably fire the e-match a voltage source is applied sufficient to cause at least the all-fire current to pass through the device for a specified time. Currents many times larger than the all-fire current still may not ignite the e-match if applied for very short intervals. Commercial e-matches come with a table or graph describing their "dynamic" behaviour with short-duration current pulses.

When computing the firing supply requirements it is important to take account of the line losses in the current loop between the supply and the e-match itself, as well as the internal resistance of the supply. The diagram and equation below can be used to calculate the minimum firing voltage given the supply internal resistance, the line resistance, the e-match resistance, and the all-fire current:

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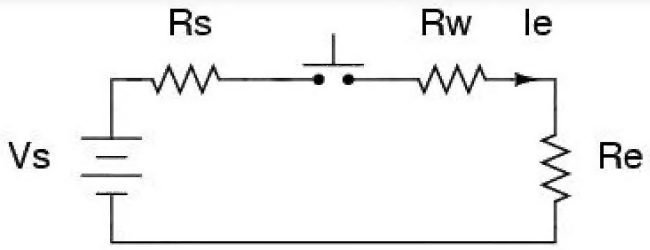


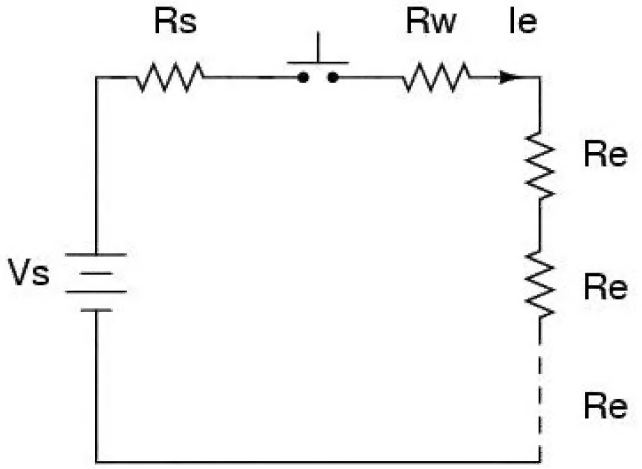
$$Vs > Ie * (Rs + Rw + Re)$$

As a simple example, take the supply internal resistance as 200 mR, the line resistance as 25 R, the match resistance as 1R5, and all-fire current as 500 mA. This results in a minimum firing voltage of 14.2 V. Ignoring the match and supply resistances would give you a figure of 12.5 V, which would not reliably ignite the e-match! In practical circuits the line resistance is typically the most dominant figure and adding "a couple of volts" over what is required by it will generally work, but be sure to do the calculation anyway.

Note that Rw figure includes *all* resistance from the battery terminals through to the binding post on the "slat" (or "rail") you are using, and the Re figure includes the resistance of the leader wires. Non-trivial resistances can accumulate, even with short lengths of hook-up wire inside slats and firing boxes.

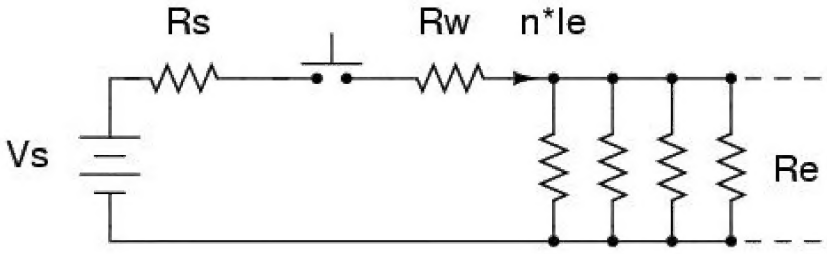
Multiple e-matches can be interconnected to initiate multiple devices at once. You have three choices in the connection topology; series, parallel, and series-parallel. Each has its own advantages and disadvantages:

Series connection is the most widely used in practice, it has the advantage of being easy to debug, as the continuity testing feature of most firing systems will detect an open joint. The individual e-match resistances accumulate slowly, requiring only an extra volt or so per additional e-match. However, as all the bridge wires are in series, should any of them open significantly before the others it is possible that not all e-matches in the loop will fire. Any significant difference in e-match resistances or pyrogen sensitivity can cause only a single match to fire, the most sensitive protecting the rest in the loop from the firing current.



$$Vs > Ie * (Rs + Rw + (n*Re))$$

Parallel connection solves this problem, all connected e-matches will fire eventually. However as all e-matches are in parallel a faulty joint in the circuit can be be hidden by other correctly connected e-matches. Parallel circuits also demand larger current requirements from the supply and put limits on the line losses. For every N matches you have, Rs and Rw become N times more important:



$$Vs > (n*Ie) * (Rs + Rw + (Re/n))$$

Series-Parallel is uncommon, but tries to make the best of both worlds. It places as many e-matches in series as you dare accept the chance of not firing correctly and as many strings on these series connected e-matches in parallel as you need in total. It is also the optimal topology for firing the largest number of e-matches from a given source resistance. This is

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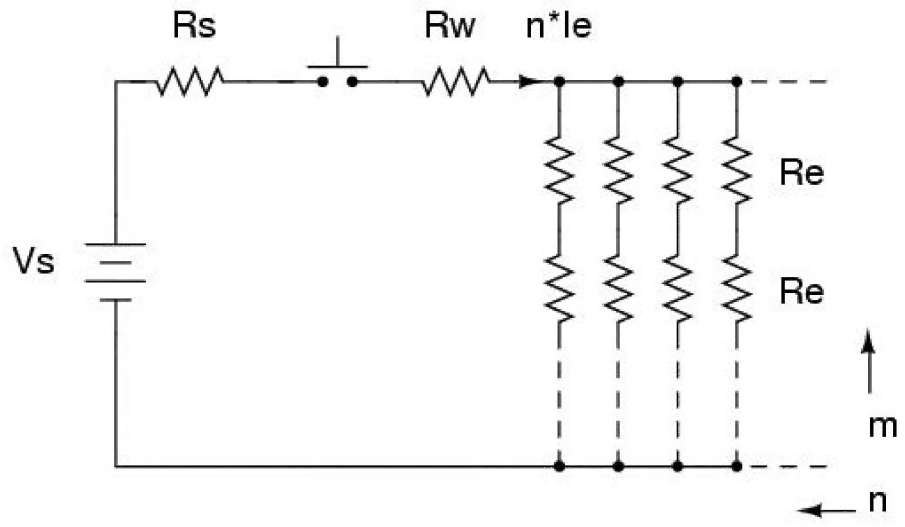
pyrotechnic devices. Such an arrangement, or a similar one fitting the same model, may be mandated by the physical arrangement of long fronts with multiple daisy-chained slats.



$$Vs > (n*Ie) * (Rs + Rw + ((m/n)*Re))$$

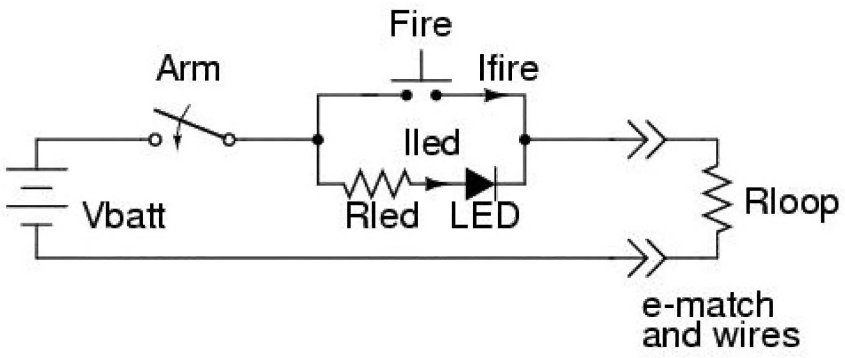
Practical Firing Boxes

A firing system can be as simple as a battery and a pair of wires which you touch to the terminals at the right moment, or a bunch of nails in a piece of timber (a "nail board" - handy for sequenced fronts). However, for safety it is best to have a somewhat more complicated arrangement. At minimum it is best to have a safety arming switch and a separate firing switch. The arming switch is best if it is physically difficult to press accidentally, a key-operated or shrouded rocker switch is ideal. The firing switch may also be shrouded for extra safety.

So called "shunt-plugs" are also a good safety feature, and are required by the standards in many countries. They simply short every shot circuit at the slat until just before testing or firing. Providing the facility to have a shunt-plug installed at the same time as a firing cable is useful, but risky in that someone may plug the other end of the cable into the firing box while you are up at the slat unplugging the shunt-plug. Generally a shunted lead is swapped for the shunt-plug and you take the key to the firing system with you out to the slat while performing the shunt-plug/firing lead swap.

Ideally your firing system should also have a continuity checking system. Activation of the continuity checker should be at the very least part of the arming procedure, if not a separate difficult to accidentally activate button. The potential exists in practical situations for the no-fire current being used to test the continuity to cook-off an e-match and prematurely discharge a pyrotechnic device, perhaps with lethal results!

Probably the most entry level firing box would be a circuit (per-channel) like this:



$$Vbatt > Ifire * Rloop$$

$$Rled > Vbatt / min(Iled, Itest)$$

$$PRled > (Iled^2) * Rled$$

Vbatt is chosen such that it can deliver the all-fire current Ifire through Rloop. Rled is chosen such that worst-case somewhat less than the no-fire current Itest passes through it (ie, setting Rloop = 0). This current must also be less than the maximum the LED is rated for, Iled. Vbatt must also be greater than the forward voltage drop of the LED or else it will never light. The power dissipation of Rled can become significant at higher Vbatts, ensure it is sufficiently rated.

Here is a picture of a simple single channel system using such a circuit:

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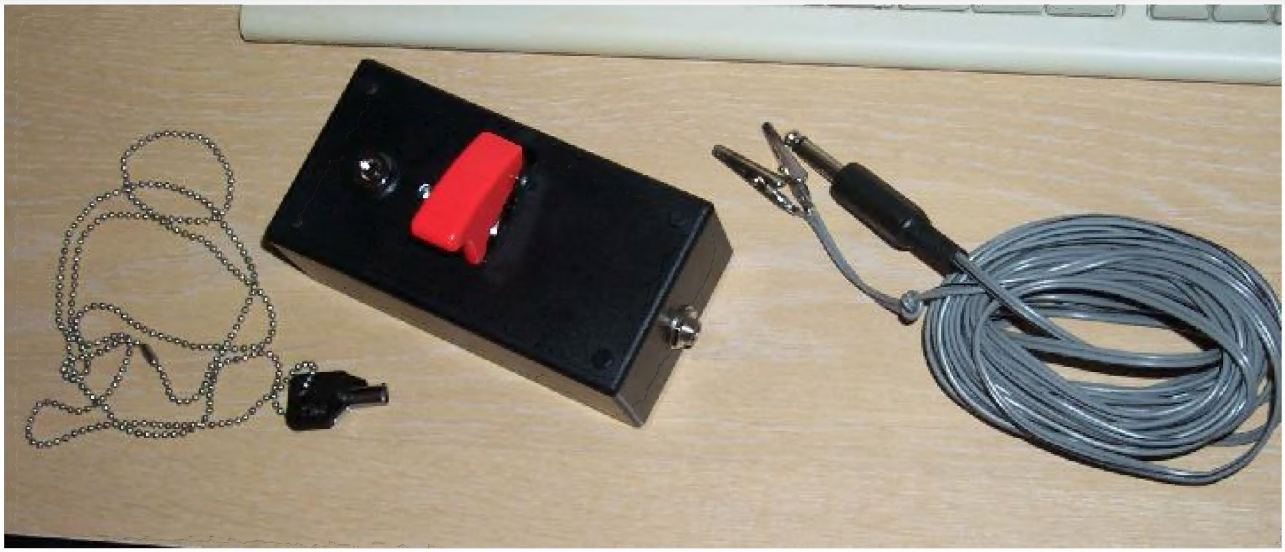

It is a simple matter to duplicate the circuit above as many times as required to build multi-channel firing boxes. Practical issues like quick interconnects between the firing box and the slats, and the slats and e-matches will drive the plug and socket selection. D-style data plugs are popular between the box and slats, they can take several Amps briefly which is more than sufficient for series connected e-matches. A D-25 system can carry 25 shots using the shell as the return, or 24 shots using one pin as the return. Multiple pins can be used for a single channel to boost current capability if required. D-type connectors make implementing shunt-plugs very easy. Spring-loaded speaker terminals are very popular for the slats, but some use binding posts for better mechanical restraint at the expense of somewhat longer set-up times.

Advanced Systems

Capacitor Discharge systems are becoming increasingly popular. They offer very high firing voltages and extremely low source resistances, capable of pushing large currents through even thin wiring. They are ideal for driving a large number of e-matches per channel at a great distance from the firing box. As smaller batteries can be used they offer a mass/volume benefit as well. Their charge-time and extra complexity tends to limit amateur construction, but modified photo flash units are easy to put together for single-channel use:

The unit above has a 130 uF capacitor which is charged to 340 V, delivering up to 7.5 J into the loop. The typical simplified circuit of a capacitive discharge firing box resembles this:

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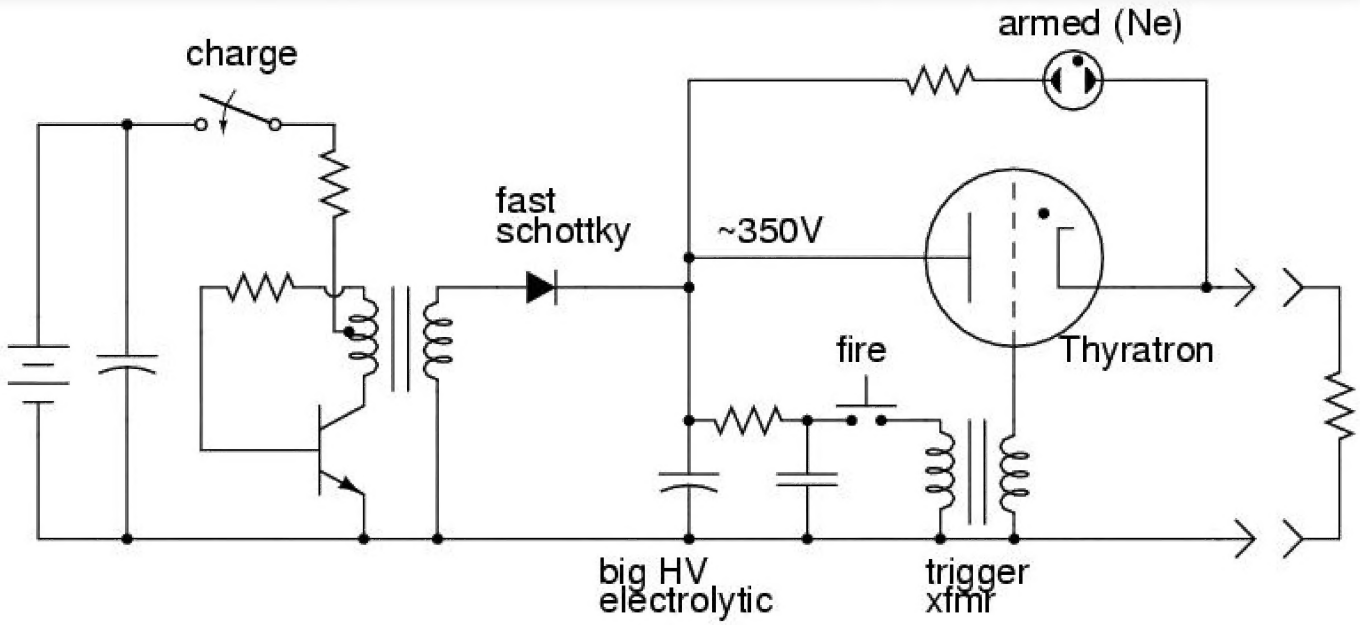

The HV capacitor(s) in such devices store **lethal** energies. Construction and use of capacitive discharge firing boxes is for experts only! There is quite a bit more to a successful circuit than show above.

Diode multiplexed, microprocessor controlled, computer driven, and RF linked systems are beyond the scope of this page, but much information can be found online about them. Anyone with sufficient electronics knowledge and attention to safety can easily build one for far less than the commercial asking price. Commercial systems are of course expedient and have some expectation of performance and reliability which many find very attractive. Be aware though that there are many commercial systems out there that are just terrible, either in design or build quality, frequently both. Quite a few builders of commercial systems found online have never used them in practice, or used them so infrequently that they don't have a good feel for making a practical rugged unit that will survive use in the hostile field environment.

Practical E-Matches

The simplest e-match is made by taking a suitable length of bell wire and bearing both ends, a short length of fine gauge nichrome is shorted across one end (preferably by soldering), and the result dipped in a slurry of black powder then allowed to dry. Almost all e-matches are also given a final coat of thick lacquer to protect and waterproof them, often nitrocellulose or cellulose acetate is used. The bare wires at the other end of the e-match are twisted together as a "safety shunt" for storage to minimize any chance of accidental ignition.

Nichrome is not the only bridge wire material that may be used. Any metal that is ductile enough to be drawn into a filament sufficiently fine to achieve the required resistance in practical dimensions can be used. Nichrome is quite difficult to solder without resorting to acid-based fluxes (which require clean-up neutralization after use) so other metals are quite desirable. Folding and crimping the lead wires to the bridge wire is popular, but no substitute for a good pair of solder joints. Fine steel threads from steel wool pads or scourers work and solder quite well, and are very cheap compared to extra-fine nichrome. Very fine copper wire can also be used but I find it unmanageably small in practice.

A more sensitive pyrogen can be used to make ignition more immediate and reliable. Typical compositions are dark flash-like. Such a sensitive composition is always prepared as a slurry and is treated with the up-most respect. The smallest amount possible is used. Usually another layer of a less sensitive composition will be coated over the top to protect the e-match and give it better ignition qualities. Metal powders or thermitic mixtures are often added to generate long-lived hot sparks for their fire-giving properties, amorphous silicon or boron are also popular additions.

As the e-match head ignites from the inside they generally explode with a loud snap and throw burning pieces of pyrogen in all directions, this is where a shroud comes in handy to direct the blast where it is needed, and keep it away from where it isn't. The shroud also protects the sensitive e-match head from accidental friction and casual impacts. Crush damage is the most likely form of abuse to cause an accidental ignition, many commercial e-matches will ignite when crushed, stepping on them is generally enough to set them off.

Peroxides of Barium or Zinc are popular oxidisers for ultra-sensitive pyrogens. Barium Chlorate is quite popular too. One must balance their requirement for a "death mix" pyrogen with safety, most commercial pyrogen compositions are quite friction sensitive and can lead to nasty accidents while matching shell leaders, especially without a shroud or with it pulled back. Having sulfur containing blackmatch stabbing into the shroud-protected e-match head is probably just as dangerous. One school of thought suggests you match the shell leader while the shell is already in the mortar with all body parts well clear for the best safety, but I prefer to make less sensitive e-matches and beef up the firing system, it gives you that extra margin of safety against accidental ignitions.

Conductive pyrogens for bridgeless e-matches typically use conductive lampblacks and/or metal powders to form a "composition resistor" around the bare lead wires. The composition and the bare leader geometry is tuned to achieve the desired resistance. Acetylene black is very conductive and a popular choice, but more modern nano-structured carbon materials are now available and could be interesting to try. The bridge wire attachment is the most time consuming part of making e-matches, so bridgeless e-matches are very attractive. However they are generally considered less reliable and more difficult to make with controlled characteristics which makes them difficult to use in series strings.

Expedient e-matches may be made by soldering commercial 1/4 Watt (or less) low value resistors to a length of bell wire and then coating with a pyrogen. Surface mount components are gaining popularity. Other expedient systems use "grain of wheat" bulbs or Christmas tree lights as pre-wired e-match heads, almost ready to be dipped (the envelope is carefully opened before applying the pyrogen). Such a construction technique has quite a following in the amateur rocketry world. In

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individual bulbs used. Narrow strips of PCB material, copper clad on both sides, are easily spiral wound with bridge wire then soldered the complete length. A fibre cut-off disk is then used to cut individual e-match "chips" that can be soldered to bell wire then dipped as usual, this is a very expedient way to make hundreds of e-match heads per hour.

As bell wire is becoming more difficult to get in Australia, I find using Cat-5 data cable pairs for e-matches quite usable. You can use stranded wire if you wish, but solid core wire is much easier to work with. Be careful, especially with bridgeless e-matches, that your pyrogen composition is compatible with the wire material, dry the pyrogen quickly to limit corrosion of the lead wires (and bridge wire), and then coat with syrupy lacquer for a good moisture seal.

Like commercial firing systems, commercial e-matches are expensive but extremely reliable. They offer very tight repeatable ratings, which is very important for series firing of large strings. For mission critical shots with cold batteries or long runs they are the only choice. **Never shoot a commercial display with homebrew e-matches**, it just isn't worth it! However being able to make a cheap e-match for testing things and other times when it just doesn't matter is quite useful.

2 comments.

Attachments

title	type	size
ematch fig source	application/octet-stream	1.377 kbytes

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